U.S. DEPARTMENT OF COMMERCE/ National Oceanic and Atmospheric Administration

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OFFICE OF THE FEDERAL COORDINATOR FOR
METEOROLOGICAL SERVICES AND SUPPORTING RESEARCH

FEDERAL METEOROLOGICAL HANDBOOK NO. 11

DOPPLER RADAR METEOROLOGICAL OBSERVATIONS

PART B
DOPPLER RADAR THEORY AND METEOROLOGY

FCM-H11B-2005

Washington, DC
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PREFACE

The Federal Coordinator for Meteorological Services and Supporting Research has the responsibility to maintain and publish Federal Meteorological Handbooks. This series of documents provides standards and procedures to facilitate the efficient collection, sharing, and use of meteorological information by agencies of the federal government and private industry.

The original Federal Meteorological Handbook, Number 11 (FMH-11), DOPPLER RADAR METEOROLOGICAL OBSERVATIONS, was prepared and published under the auspices of the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) at the request of the Next Generation Weather Radar (NEXRAD) Program Council and in coordination with the federal agencies that are represented on the Interdepartmental Committee for Meteorological Services and Supporting Research. The purpose of FMH-11 is to standardize, insofar as practical, the operation of the Weather Surveillance Radar-1988, Doppler (WSR-88D) systems and the procedures used by personnel of the Departments of Commerce, Defense, and Transportation. By approving publication of this handbook, those agencies have agreed to operate their WSR-88D systems accordingly. Some flexibility under certain meteorological, siting, or mission circumstances is permitted to enhance the quality and utility of some WSR-88D products.

The revision process is dependent on the evolution of WSR-88D subsystems software and products. Part A has been revised to ensure it provides users current operations guidance. Parts B, C, and D are being revised in a separate effort principally through the guidance of the Radar Operations Center (ROC). All revisions are coordinated among the NEXRAD triagencies (Department of Commerce (DoC), Department of Defense (DoD), and Department of Transportation (DoT)); thus, they possess the same authority as the initial edition of FMH-11.

The agencies shall review the documents at least annually. The goal is to review and update (as necessary) the handbooks as part of every WSR-88D software build release. Suggestions for modifications and additions shall be forwarded through the appropriate channels in each agency for consideration, and issuance, if appropriate. Changes will be issued as a total update of each chapter of the handbook. The handbook updates will be issued in electronic format and made available on the OFCM home page (http://www.ofcm.gov). Readers can make copies of the handbook without a request for approval from the OFCM. A summary of changes made during updates will be annotated in the preface of each part.

Each major part of the FMH-11 is designed to stand alone, except where cross references avoid voluminous redundancy. In all, FMH-11 has four parts:

Part A - System Concepts, Responsibilities, and Procedures (December 2005)

Part B - Doppler Radar Theory and Meteorology (December 2005)

Part C - WSR-88D Products and Algorithms (February 1991)

Part D - WSR-88D Unit Description and Operational Applications (April 1992)

Part B brings together in one document most of the theory required to understand how the WSR-88D acquires and processes the Doppler radar signal. It presents mathematical formulations of the physical processes and laws, explains how the Doppler technology "sees" various meteorological and hydrological events, and explores the strengths and problems in data acquisition with a Doppler radar. It then addresses aspects of radar meteorology regarding recognition of velocity patterns and applications of Doppler radar to storm events.

Summary of Changes:
This version of Part B updates and replaces the original document, published in June, 1990. This version updates the document as of Radar Product Generator Build 6 (released in September 2004) and provides updated information related to large-scale precipitation weather systems and individual thunderstorms and attendant phenomena. The section related to hurricanes has been deleted, but may be updated and included in a future version.

Samuel P. Williamson
Federal Coordinator for Meteorological
Services and Supporting Research

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LIST OF SYMBOLS

a	Radius
A	Signal Amplitude
A_e	Effective Aperture Area of the Antenna
b	Gain Constant
c	Speed of Light = 3×10^8 m s^{-1}
dB	Decibel
D	Drop Size
D_e	Diameter of an Equivalent Volume Spherical Raindrop
f	Frequency
f_d	Doppler Frequency
f_n	Nyquist Frequency
f_s	Sampling Frequency
G	Gain
h	Height
h_s	Surface Height
I	Inphase Component of the Complex Signal
k	Multiplicative Factor Determined by Refraction Index Profile
$k \cdot a$	Equivalent Earth's Radius
K	Complex Index of Refraction
K_p	Two-Way Attenuation
L	Loss Factor
M	Modified Index of Refraction; Mass Liquid Water Content
n	Index of Refraction
N	Refractivity = $(n - 1) \times 10^6$
N_o	Number Density (Number of Particles Per Unit Volume)
P	Pressure
P_i	Incident Power Density
P_r	Echo (Return) Power
P_t	Peak Transmitted Power
Q	Quadrature Phase Component of the Complex Signal

r	Range to Target
r_a	Unambiguous Range
r_c	Core Radius
R	Rainfall Rate
S	Signal Power
t	Time
T	Air Temperature, $^\circ$ Kelvin
U	Gating Function
v	Velocity
v_a	Unambiguous Velocity
v_d	Doppler Velocity
v_h	Average Horizontal Wind Velocity Around the Scanning Circle at Height h
v_m	Measured Velocity
v_r	Radial Component of Velocity
v_t	Terminal Fall Velocity for Precipitation Particles
v_T	True Velocity
v_x	Maximum Velocity
V	Voltage
W	Spectrum Width
Z	Reflectivity
Z_e	Equivalent (Effective) Radar Reflectivity Factor
α	Antenna Rotation Rate
β	Azimuth Angle Measured from the Upwind Direction
Δ_θ	Angular Sampling Interval
Δ_ϕ	Angular Increment
ε	Partial Pressure of Water Vapor, Millibars; Dielectric Constant
η	Target Backscattering Cross Section Per Unit Volume
θ	Angular Distance from Beam Axis
θ_e	Equivalent Angular Distance from Beam Axis
θ_m	Measured Angular Distance from Beam Axis
θ_T	True Angular Distance from Beam Axis

θ_2 Two-way Antenna 3dB Beam Width

θ_{3dB} Antenna Horizontal Half-Power Beam Width

λ Radar Wavelength

ρ Vapor Pressure

σ_b Target Backscattering Cross Section

σ_d^2 Variance Due to Drop Size Distribution

σ_{do} Standard Deviation of Drop Terminal Velocities

σ_f Frequency Standard Deviation

σ_r^2 Variance Due to Antenna Motion

σ_s^2 Variance Due to Wind Shear

σ_t Time Standard Deviation

σ_t^2 Variance Due to Turbulence

σ_v Standard Deviation of the Velocity Spectrum

τ Pulse Width (Duration)

ϕ Vertical Distance from Beam Axis

ϕ_e Elevation Angle

ϕ_{3dB} Antenna Vertical Half-Power Beam Signal

ψ Initial Phase of Transmitter Signal

ω Angular Velocity